AFRL-VS-TR-2002-1552

MAGNETOSPHERIC STRUCTURE AND DYNAMICS: A MULTISATELLITE APPROACH

W. Jeffrey Hughes

Boston University
Center for Space Research
725 Commonwealth Avenue
Boston, MA 02115-1401

May 2000

Final Report

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

AIR FORCE RESEARCH LABORATORY
Space Vehicles Directorate
29 Randolph Road
AIR FORCE MATERIEL COMMAND
HANSCOM AIR FORCE BASE MA 01731-3010

"This technical report has been reviewed and is approved for publication"

2 May 02

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
23 April 2002

3. REPORT TYPE AND DATES COVERED
FINAL REPORT (SUMMARY)

4. TITLE AND SUBTITLE
Magnetospheric Structure and Dynamics: A Multisatellite Approach

5. FUNDING NUMBERS
PE: 61102F
PR: 7601
TA: 18
WU: JA

Contract #: F19628-90-K-0003

6. AUTHOR(S)
W. Jeffrey Hughes

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Boston University
Center for Space Physics
725 Commonwealth Avenue
Boston, MA 02115-1401

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory
29 Randolph Road
Hanscom AFB MA 01731-3010

Contract Manager: Janet Johnston/VSBX

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-VS-TR-2002-1552

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This contract focused on five areas of scientific investigation in which significant progress was made during the life of the contract; electrostatic electronic cyclotron harmonic emissions observed by CRRES; the implications of cross tail plasma gradients on the structure of the auroral zone, plasma distributions in the topside ionosphere; waves and fluctuations seen in the cusp; and ion cyclotron wave group delays.

14. SUBJECT TERMS

Electrostatic electron	CRRES
Plasma gradients	Magnetospheric tail
Plasma distributions	

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

Standard Form 298 (Rev. 2-89) (EG)
Prescribed by ANSI Std. 239.18
Designed using Perform Pro, WHS/DIOR, Oct 94

I. Introduction

This contract funded a comprehensive nine-year study of magnetospheric structure and dynamics. There are three major areas of study: waves and wave particle interactions, magnetospheric tail and substorm dynamics, ionosphere-magnetosphere coupling. All three are central to our understanding of the geoplasma environment. Each plays a critical part in determining the pattern of plasma flows and currents and the distribution and properties of the plasma and energetic particles within the magnetospheric-ionosphere system. The major effort was directed towards the analysis of existing and newly acquired spacecraft data, with particular emphasis on multi-satellite studies. The data analysis was complemented with theoretical and simulation studies, the development and maintenance of data analysis and display software for use in the data analysis, and the design of new innovative plasma and field instruments for use in the next generation of spacecraft. The overall goal of the study was to provide the understanding of the magnetosphere-ionosphere system needed to construct reliable models that will forecast the future state of the system.

This report focuses on five areas of scientific investigation in which significant progress was made during the life of the contract: electrostatic electron cyclotron harmonic emissions observed by CRRES; the implications of cross tail plasma gradients on the structure of the auroral zone; plasma distributions in the topside ionosphere: waves and fluctuations seen in the cusp: and ion cyclotron wave group delays. A complete list of the 34 refereed publications arising out of the research funded by this contract is contained in the last section of this report.

In addition to this activity, Mr. Peter Anderson made significant advances in developing an imager to observe emissions from solar coronal mass ejections. This work has resulted in an instrument that will soon be launched into space.

II. Scientific Results

1. Banded Harmonic Electrostatic Emissions

We surveyed banded electronic emissions observed by the Plasma Wave Experiment on the CRRES spacecraft with an emphasis on the relation of the frequency of the highest intensity waves to multiples of the local electron cyclotron frequency. Emissions were detected chiefly in the postmidnight quadrant of the magnetosphere between L=3.5 and L=7. We confirmed that high-intensity emissions are confined to within a few degrees of the magnetic equator. The emissions were all measured below the electron plasma frequency, and we found they generally favor the upper part of the gyroharmonic interval. When ECH emissions are detected both near and far from the equator on the same orbit, it is generally true that a broad band of the same relative frequency emissions are excited in both locations. The difference is that near the equator, a few frequency channels measure much higher intensities. Comparison of our observations with a convective growth model calculation, showed that the observed spectra were not consistent with predicted ones.

Principal Reference: Paranicas, C., W.J. Hughes, H.J. Singer, and R.R. Anderson. Banded electrostatic emission observed by the CRESS plasma wave experiment. *J. Geophy. Res., 97,* 13,889, 1992.

2. Cross Tail Plasma Gradients

We developed a natural explanation of the Harang discontinuity that arises from the asymmetry of ion drift paths in the tail. The Harang discontinuity is the locus of points in the nightside auroral zone across which the meridional component of the ionospheric electric field reverses from a basically poleward field on the equatorward side to a basically equatorward field on the poleward side. In other words, the Harang discontinuity represents a convergence of ionospheric electric field. The overall structure of this feature is evident in high-latitude radar observations, and in satellite measurements of both electric fields and ionospheric flows.

Ions in the plasma sheet drift westward or duskward across the tail due to the magnetic gradient and curvature drifts. The westward curvature and gradient drift depletes dawnside flux tubes of energetic ions because there is no strong source of energetic plasma in the dawnside magnetopause boundary layer to replace those that have drifted westward. This dawnside depletion effect means that, on average, the duskside of the plasma sheet will have higher ion temperatures, pressures and flux tube contents, and hence stronger westward cross-tail drift current, than the dawnside. The deficit of dawnside current (or surplus of duskside current) must be compensated by upward currents from the ionosphere distributed across the tail to ensure current continuity. In the ionosphere, closure of this current requires a convergence of ionospheric Pedersen currents, and hence a convergence of electric field, directed towards the center of the upward current. This is exactly the form of the Harang discontinuity.

Principal Reference: Erickson, G.M., R. W. Spiro and R.A. Wolf, The Physics of the Harang Discontinuity, *J. Geophys. Res.*, *96*, 1633, 1991.

3. The Low-Latitude Topside Ionosphere Near Solar Minimum

We used the retarding potential analyzer on the DMSP F8 satellite to measure ion density, composition, temperature, and ram flow velocity at 840-km altitude near the dawn and dusk meridians close to solar minimum. Nine days of data were selected for study to represent the summer and winter solstices and the autumnal equinox under quiet, moderately active, and disturbed geomagnetic conditions. The observations revealed extensive regions of light-ion dominance along both the dawn and dusk legs of the DMSP F8 orbit. These regions showed seasonal, longitudinal, and geomagnetic control, with light ions commonly predominating in places where the subsatellite ionosphere was relatively cold. Field-aligned plasma flows also were detected. In the morning, ions flowed toward the equator from both sides. In the evening, DMSP F8 detected flows that either diverged away from the equator or were directed toward the northern hemisphere. The effects of diurnal variations in plasma pressure gradients in the ionosphere and plasmasphere, momentum coupling between neutral winds and ions at the feet of field lines, and **E x B** drifts qualitatively explain most features of these composition and velocity measurements.

Principal Reference: Greenspan, M.E., W.J. Burke, F.J. Rich, W.J. Hughes, and R.A Heelis, DMSP F8 observations of the mid-latitude and low-latitude topside ionosphere near solar minimum, *J. Geophys. Res., 99*, 3817, 1994.

4. Electric and Magnetic Field Fluctuations In the Cusp

Low altitude satellites provide snapshot-like images of ionospheric cusp/cleft regions that reflect processes taking place near the dayside magnetopause. These regions are characterized by rapid fluctuations in both electric and magnetic fields which are collocated with intense fluxes of low-energy, magnetosheath-like particles and often exhibit very narrow, spike-like features. We analyzed the electric and magnetic field fluctuations detected during approximately seventy crossings through the dayside ionosphere by the DE-2 satellite, when the IMF had a southward component. The data span three hours (10-13) in magnetic local time. The electric field fluctuations usually increased sharply at the low-latitude edge of the enhanced soft electron precipitation. Fluctuations with scale sizes greater than 10 km are consistent with steady field-aligned currents closing by ionospheric Pedersen currents. For fluctuations with smaller spatial/temporal scale sizes there is evidence for hydromagnetic wave activity. Here the ratios of electric to magnetic field amplitudes indicate the superposition of Alfvén waves and stationary field-aligned currents.

Principal Reference: Basinska, E.M., W.J. Burke, N.C. Maynard, W.J. Hughes, D.J. Knudsen, and J.A. Slavin. Electric and Magnetic Field Fluctuations at High Latitudes in the Dayside Ionosphere During Southward IMF. in Solar Wind Sources of ULF Waves, (Ed. M.J. Engebretson, K. Takahashi and M. Scholer), AGU Geophys. Mono. Ser., v81, p.387, Am. Geophys. Un., 1994.

5. Ion Cyclotron Group Delay near the Plasmapause

Electromagnetic ion cyclotron waves are generated near the magnetic equator though an instability driven by energetic ion temperature anisotropy. The waves propagate along magnetic flux tubes, and many are observed on the ground as pc1 magnetic pulsations. These often exhibit a distinctive wave packet structure believed to be the results of wave packets bouncing back and forth along a flux tube producing the repetitive structure that gives rise to the name pearl pulsations. We compared ion cyclotron waves observed by the DE 1 spacecraft near the equatorial plane near L=4 with ground based observations of pc1 pulsations observed near the foot of the DE1 field line by the AFGL Magnetometer Network, and estimated the delay time for the signal to propagate from the equator to the ground. The estimates for the different events ranged between 35 and 100s.

We compared these measurements with calculations of the group delay made using the full hot plasma dispersion relation integrated along a dipole field line from the equator to the ground. The plasma parameters used in the calculations are based on the plasma and particle measurements made by DE 1 at the time of the wave events.

We found that the density of both the hot and cold species affect the wave group velocity significantly, especially near the equatorial plane where the group velocity is smallest, and where it has the largest effect on the total group delay.

Principal Reference: Ludlow, G.R., and W.J. Hughes. The Ion Cyclotron Group Delay of Source Regions near the Plasmapause, *J. Geophys. Res.*, 98, 7561, 1993.

III. Contributing Scientists and Staff

Boston University:

W.J. Hughes, Principal Investigator, Professor
P. Andersen, Sen. Project Engineer
E.M. Basinska, Research Associate
G.M. Erickson, Assistant Research Professor
M.E. Greenspan, Research Associate
R.V. Hilmer, Research Associate
J. James, Research Programmer
D. Koonce, Research Programmer
G.R. Ludlow, Research Associate
M. Meehan, Assistant Computer Technician
C. Paranicas, Assistant Research Professor

Air Force Geophysics Laboratory:

W. J. Burke
M. Heinemann
N.C. Maynard
H.J. Singer

IV. Published Papers

Baker K.B., R.A. Greenwald, J.M. Ruohoniemi, J.R. Dudney, M. Pinnock, P.T. Newell, M.E. Greespan, and C. –I. Meng, Simultaneous HF-Radar and DMSP Observations of the Cusp, *Geophy. Res. Lett. 11*, 1869-1872, 1990.

Basinska, E.M., W.J. Burke and N.C. Maynard, Electric and Magnetic Field Fluctuations in the Cusp/Cleft Regions, in *Physics of Space Plasmas* 1990, SPI Conference Proceedings and Reprint Series, Number 10, (T. Chang, G. B. Crew, and J.R. Jasperese, eds.) p. 153, Scientific Publishers, Cambridge, Mass., 1991.

Basinska, E.M., W.J. Burke, N.C. Maynard, W.J. Hughes, J.D. Winningham, and W.B. Hanson, Small-scale electrodynamics of the cusp with northward IMF, *J. Geophys. Res., 97*, 6369, 1992.

Basinska, E.M., W.J. Burke, N.C. Maynard, W.J. Hughes, D.J. Knudsen, and J.A. Slavin, Electric and magnetic field fluctuations at high latitudes in the dayside ionosphere during southward IMF, in Solar Wind Sources of ULF Waves, (Ed. M.J. Engebretson, K. Takahashi and M. Scholer), AGU Geophys. Mono. Ser., v81, p.387, Am. Geophys. Un., 1994.

Batista, I.S., E.R. de Paula, M.A. Abdu, N.B. Trivedi, and M.E. Greenspan, Ionospheric effects of the March 13, 2989, magnetic storm at low and equatorial latitudes, *J. Geophys. Res., 96*, 13943, 1991.

Burke, W.J., J.S. Machuzak, N.C. Maynard, E.M. Basinska, G.M. Erickson, R.A Hoffman, J.A. Slavin and W.B. Hanson, Electrodynamic signatures of the plasma sheet boundary layer in the evening ionosphere, in *Physical Signatures of Magnetospheric Boundary Layer Processes*, (Eds. J.A. Holtet and A. Egeland), p. 111, Kluwer, Dordrecht, 1994.

Burke, W.J., E.M. Basinska, N.C. Maynard, W.B. Hanson, J.A. Slavin and J.D. Winningham, Polar cap potentials during periods of positive and northward IMF, *J. Atmos. Terr. Phys., 56,* 209, 1994.

Burke, W.J., J.S. Machusak, N.C. Maynard, E.M. Basinska, G.M. Erickson, R.A. Hoffman, J.A. Slavin and W.B. Hanson, Auroral ionospheric signatures of the plasma sheet boundary layer, *J. Geophys. Res., 99,* 2489, 1994.

Chi, P.J., C.T. Russell, G. Le, W.J. Hughes, and H.J. Singer, A synoptic Study of Pc 3, 4 Waves using the Air Force Geophysics Laboratory Magnetometer Array, *J. Geophys. Res.,* 101,13215, 1996.

Egeland, A., W.J. Burke, N.C. Maynard, E.M. Basinska, J.D. Winningham, and C.S. Deehr, Ground and Satellite Observations of postdawn aurorae near the time of a sudden storm, *J. Geophys. Res., 99, 2095.*

Erickson, G.M. R.W. Spiro, and R.A. Wolf, The physics of the Harang Discontinuity, *J. Gepohys. Res., 96,* 1633, 1991.

Erickson, G.M., A quasi-static magnetospheric convection model in two dimensions, *J. Geophys. Res., 97,* 6505, 1992.

Escoubet, C.P., M.F. Smith, S.F. Fung, P.C. Anderson, R.A. Hoffman, E.M. Basinska, and J.M. Bosqued, Staircase ion signature in the polar cusp: A case study, *Geophys. Res. Lett., 19,* 1735, 1992.

Fraser, B., H.J. Singer, W.J. Hughes, J.R. Wygant, R.R. Anderson, and Y.D. Hu, CRRES Poynting Vector Observations of Electromagnetic Ion Cyclotron Waves near the Plasmapause, *J. Geophys. Res., 101,* 15331, 1996.

Freeman, M.P., C.J. Farrugia, L.F. Burlaga, M.R. Hairton, M.E. Greenspan, J.M. Ruohoniemi, and R.P. Lepping, The Interaction of a Magnetic Cloud with the Earth: Ionospheric Convection in the Northern and Southern Hemispheres for a Wide Range of Quasi-Steady Interplanetary Magnetic Field Conditions, *J. Geophys. Res. 98*, 7633, 1993.

Greenspan, M.E., C.E. Rasmussen, W.J. Burke, and M.A. Abdu, Equatorial density depletions observed at 840 km during the great magnetic storm of March, 1989, *J. Geophys. Res., 96,* 13931, 1991.

Greenspan, E.E., W.J. Burke, F.J. Rich, W.J. Hughes, and R.A. Heelis, DMSP F8 observations of the mid-latitude and low-latitude topside ionosphere near solar minimum, J. Geophys. Res., 99, 3817, 1994.

Heinemann, M., G.M. Erickson, and D.H. Pontius, Jr., Inertial currents in isotropic plasma, *J. Geophys Res., 99,* 8635, 1994.

Hilmer, R.V., and G. H. Voigt, A magnetospheric magnetic field model with flexible current systems driven by independent physical parameters, *J. Geophys. Res., 100,* 5613-5636, 1995.

Hughes, W.J., Magnetospheric ULF Waves: A tutorial with a historical perspective, in *Solar Wind Sources of Magnetospheric ULF Waves,* (Eds. M.J. Engebretson, K. Takahashi and M. Scholer), AGU Geophys. Mono, 81, p.1, AGU, Washington DC, 1994.

Ludlow, G.R., and W.J. Hughes, The Ion Cyclotron Group Delay for Source Regions near the Plasmapause, *J. Geophys. Res. 98,* 7561, 1993.

Maynard, N.C., T.L. Aggson, E.M. Basinska, W.J. Burke, P. Craven, W.K. Peterson, M. Sugiura, and D.R. Weimer, Magnetospheric Boundary Dynamics: DE-1 and DE-2 Observations near the Magntopause and Cusp, *J. Geophys. Re., 96,* 3505, 1991.

Maynard, N.C. W.J. Burke, W.F. Denig, and E.M. Basinska, Ionospheric footprints of the outer magnetosphere: satellite observations, in *Physics of the Magnetopause,* (eds. P. Song, B.O.U. Sonnerup, and M. Thomsen) AGU Geophys. Mono. Ser., V90, 395, 1995.

Maynard, N.C., W.J. Burke, W.F. Denig and E.M. Basinska, Signatures and sources of electric fields and particles at dayside high latitudes, in *Physical Signatures of Magnetospheric Boundary Layer Processes*, (Eds. J.A. Holtet and A. Egeland, p. 59, Kluwer, Dordrecht, 1994.

Maynard, N.C. W.J. Burke, E.M. Basinska, G.M. Erickson, W.J. Hughes, H.J., Singer, A. Yahin, D.A. Hardy, and F.S. Mozer, Dynamics of the inner magnetosphere near times of substorm onsets, *J. Geophy. Res., 101,* 7705, 1996.

Newell, P.T., W.J. Burke, C.-I. Meng, E.R. Sanchez, and M.E. Greenspan, Identification and Observations of the Plasma Mantle at low altitudes, *J. Geophys. Res., 96,* 35, 1991.

Newell, P.T., W.J. Burke, E.R. Sanchez, C.-I. Meng, M.E. Greenspan and C.R. Clauer, The low latitude boundary layer and the boundary plasma sheet at low altitude: prenoon precipation regions and convection reversal boundaries, *J. Geophys. Res. 96, 21013, 1991.*

Paranicas C., W.J. Hughes, H.J. Singer, and R.R. Anderson, Banded electrostatic emissions observed by the CRRES plasma wave experiment, *J. Geophys. Res., 97,* 13889, 1992.

Paranicas, C. Observations of wavelength and convection of electron cyclotron Harmonics, *Geophys, Res. Lett., 20,* 1779, 1993.

Pinnock, M., A.S. Rodger, R.R. Dudeney, K.B. Baker, P.T. Newell, R.A. Greenwald, and M.E. Greenspan, Observations of an Enhanced Convection Channel in the Cusp Ionosphere, *J. Geophys. Res. 98*, 3767, 1993.

Rasinkangas, R., K. Mursula, G. Kremser, H.J. Singer, B.J. Fraser, A. Korth, and W.J. Hughes, Simultaneous occurrence of Pc5 and Pc 1 pulsations in the dawnside magnetosphere: CRRES observations, in *Solar Wind Sources of Magnetospheric ULF waves*, (Eds. M.J. Engebretson, K. Takahashi, and M.Scholer,) AGU Geophys. Mono., 81, p. 417, AGU, Washington DC, 1994.

Rasmussen, C.E., and M.E. Greenspan, Plasma transport in the equatorial ionosphere during the great magnetic storm of March 1989, *J. Geophys. Res. 98,* 285, 1993.

Rubin, A.G., W.J. Burke, E.M. Basinska, R. Lambour, R. Hilmer, and D.A. Hardy, Energetic electron dropouts detected by CRRES, submitted to *J. Geophys. Res.*, 1995.

Wolf, R.A., J.W. Freeman, B.A. Hausman, R.W. Spiro, R.V. Hilmer, and R.L. Lambour, Modeling Convection Effects in Magnetic Storms, in *Magnetic Storms*, (Eds. B.T. Tsurutani, W.D. Gonbzalez, Y. Kamide, and J.K. Arballo) AGU Geophys. Mono., 98, p. 161, AGU, Washington, DC 1997